

AD-777 177

ENGINEERING DESIGN DATA FOR ALUMINUM
ALLOY 2124-T851 THICK PLATE

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Dayton University

Prepared for:

Air Force Materials Laboratory

January 1974

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AD-777177

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Security Classification

DOCUMENT CONTROL DATA - R & D		
(Security classification of title, body of abstract and indexing annotation must be entered when the overall report is classified)		
1. ORIGINATING ACTIVITY (Corporate author) University of Dayton Research Institute 300 College Park Avenue Dayton, Ohio 45469		2a. REPORT SECURITY CLASSIFICATION UNCLASSIFIED
		2b. GROUP N/A
3. REPORT TITLE ENGINEERING DESIGN DATA FOR ALUMINUM ALLOY 2124-T851 THICK PLATE		
4. DESCRIPTIVE NOTES (Type of report and inclusive dates) Technical Report, August 1972 to September 1973		
5. AUTHOR(s) (First name, middle initial, last name) Kim A. Fudge Raymond E. Jones		
6. REPORT DATE January 1974	7a. TOTAL NO. OF PAGES 23	7b. NO. OF REFS 3
8a. CONTRACT OR GRANT NO. F33615-72-C-1282	9a. ORIGINATOR'S REPORT NUMBER(S) UDRI-TR-73-63	
8b. PROJECT NO. 7381	9b. OTHER REPORT NO(S) (Any other numbers that may be assigned this report)	
8c. Task No. 738106	AFML-TR-73-310	
10. DISTRIBUTION STATEMENT Approved for public release; distribution unlimited.		
11. SUPPLEMENTARY NOTES		12. SPONSORING MILITARY ACTIVITY Air Force Materials Laboratory Air Force Systems Command Wright-Patterson AFB, Ohio
13. ABSTRACT Tensile, fracture, fatigue, fatigue crack growth, and stress corrosion properties for aluminum alloy 2124-T851 thick plate were determined. The material was obtained from the Aluminum Company of America (ALCOA). Material property comparisons were then drawn between the 2124-T851 alloy and its parent alloy, 2024, in the T851 condition. A comparison of the mechanical properties of aluminum alloy 2124-T851 and 2024-T851 revealed that the 2124-T851 alloy exhibited similar tensile properties with possibly less short transverse ductility, superior fracture toughness, comparable fatigue properties with slightly lower smooth fatigue resistance, and identical fatigue crack growth rates. The 2124-T851 alloy also demonstrated good stress corrosion resistance.		

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14. KEY WORDS	LINK A		LINK B		LINK C	
	ROLE	WT	ROLE	WT	ROLE	WT
Aluminum Alloy 2124-T851						
Tensile						
Fracture Toughness						
Fatigue						
Fatigue Crack Growth						
Design Data						

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UNCLASSIFIED

Security Classification

U.S. Government Printing Office: 1974 - 758-6/2/64*

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K. A. FUDGE
R. E. JONES

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PROCESSED
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FOREWORD

This report was prepared by the University of Dayton Research Institute (UDRI), Dayton, Ohio. The work was performed under USAF Contract No. F33615-72-C-1282. The contract was initiated under Project No. 7381, "Materials Applications", Task No. 738106, "Engineering and Design Data", and administered by the Air Force Materials Laboratory, Wright-Patterson Air Force Base, Ohio, Mr. David C. Watson, AFML/MXE, Project Monitor.

All (or many) of the items compared in this report were commercial items that were not developed or manufactured to meet Government specifications, to withstand the tests to which they were subjected, or to operate as applied during this study. Any failure to meet the objectives of this study is no reflection on any of the commercial items discussed herein or on any manufacturer.

The authors would like to acknowledge that testing performed for this program was accomplished by Messrs. Eblin and Woleslagle of the UDRI.

The report covers work conducted from August 1972 to September 1973.

The report was submitted by the authors in October 1973.

This technical report has been reviewed and is approved.



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ABSTRACT

Tensile, fracture, fatigue, fatigue crack growth, and stress corrosion properties for aluminum alloy 2124-T851 thick plate were determined. The material was obtained from the Aluminum Company of America (ALCOA). Material property comparisons were then drawn between the 2124-T851 alloy and its parent alloy, 2024, in the T851 condition.

A comparison of the mechanical properties of specimens from a single plate of aluminum alloy 2124-T851 and 2024-T851 revealed that the 2124-T851 alloy exhibited similar tensile properties, less short transverse ductility, superior fracture toughness, comparable fatigue properties with slightly lower smooth fatigue resistance, and identical fatigue crack growth rates. The 2124-T851 alloy demonstrated good stress corrosion resistance.

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SECTION I

INTRODUCTION

The purpose of this program was to develop engineering design data for aluminum alloy 2124-T851 thick plate. According to the Aluminum Company of America (ALCOA), the 2124-T851 thick plate offers superior fracture toughness and short transverse ductility relative to the 2024-T851 alloy. Aluminum alloy 2124 is essentially the same as alloy 2024 except that there are tighter chemical composition requirements for the silicon, iron, and titanium alloying elements in the 2124 alloy.

Tensile, fatigue, fatigue crack growth, fracture, and stress corrosion properties of a plate of 2124-T851 aluminum alloy were determined and comparisons drawn to the mechanical properties of aluminum alloy 2024-T851.

SECTION II

MATERIAL AND SPECIMENS

The test material was a 2-1/2-inch-thick plate of aluminum alloy 2124-T851 obtained from the Aluminum Company of America (ALCOA), lot number 732-631, with a certified nominal chemical composition of:

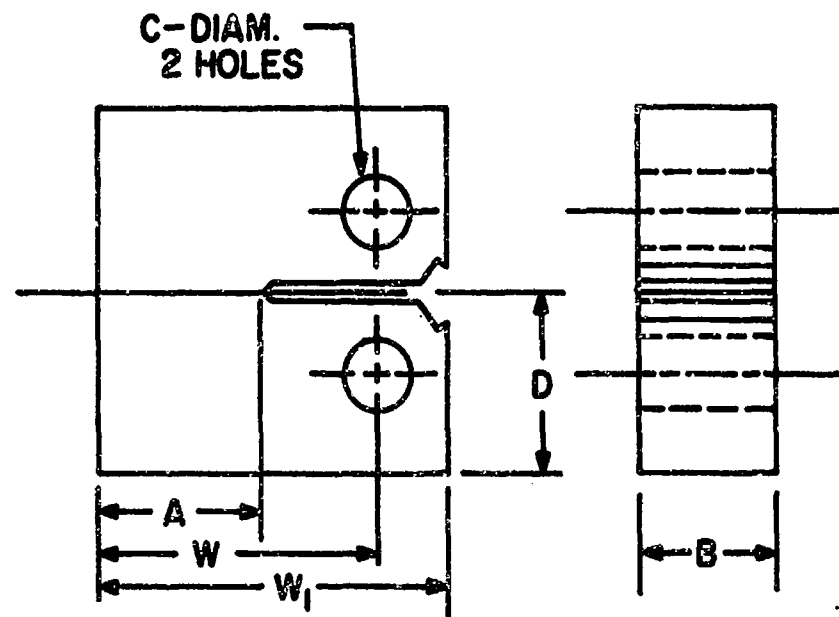
CHEMICAL COMPOSITION

(wt. %)

Silicon	Iron	Copper	Manganese	Magnesium	Chromium
0.20 max	0.030 max	4.9 max 3.8 min	0.9 max 0.30 min	1.8 max 1.2 min	0.10 max

Zinc	Titanium	Others	Aluminum
0.25 max	0.15 max	0.05 each 0.15 total max	balance

Tensile specimens were machined from the plate to the configuration shown in Figure 1. Fracture toughness, fatigue crack growth, and stress corrosion testing employed 1.00-inch-thick, 0.75-inch-thick, and 0.50-inch-thick compact tension specimens, respectively. The compact tension specimen configurations are depicted in Figure 3. The fatigue tests were performed using conventional smooth and notched specimens shown in Figures 3 and 4, respectively.



DIMENSIONS

SPECIMEN THICKNESS (INCHES)	A	B	W	W_1	D	C
(a) 1	1.220	1.000	2.000	2.500	1.200	0.500
(b) 3/4	1.150	0.750	1.500	1.875	0.900	0.375
(c) 1/2	0.800	0.500	1.000	1.250	0.600	0.250

Figure 2. Compact Tension Specimen Configuration.

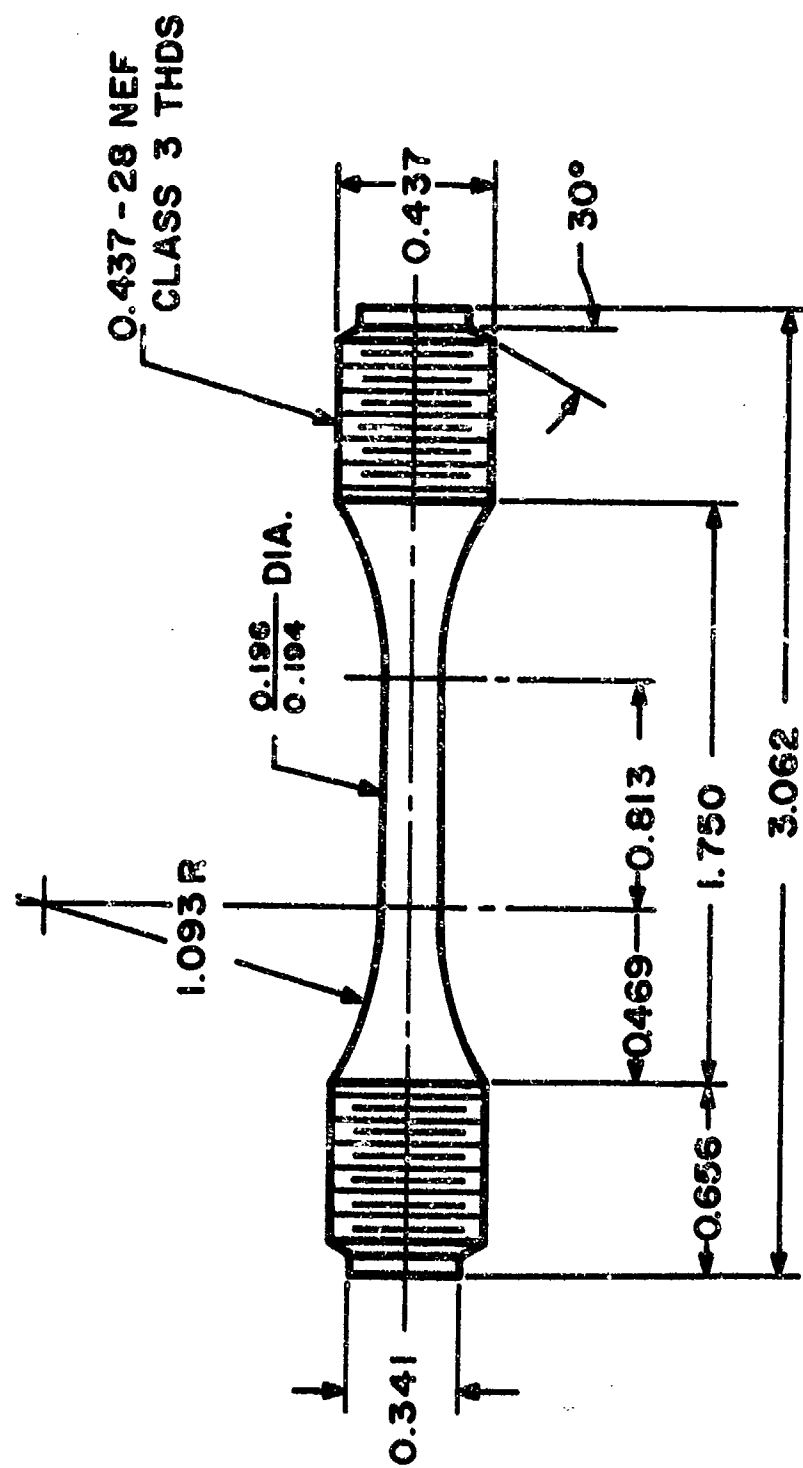


Figure 3. Smooth Fatigue Specimen Configuration.

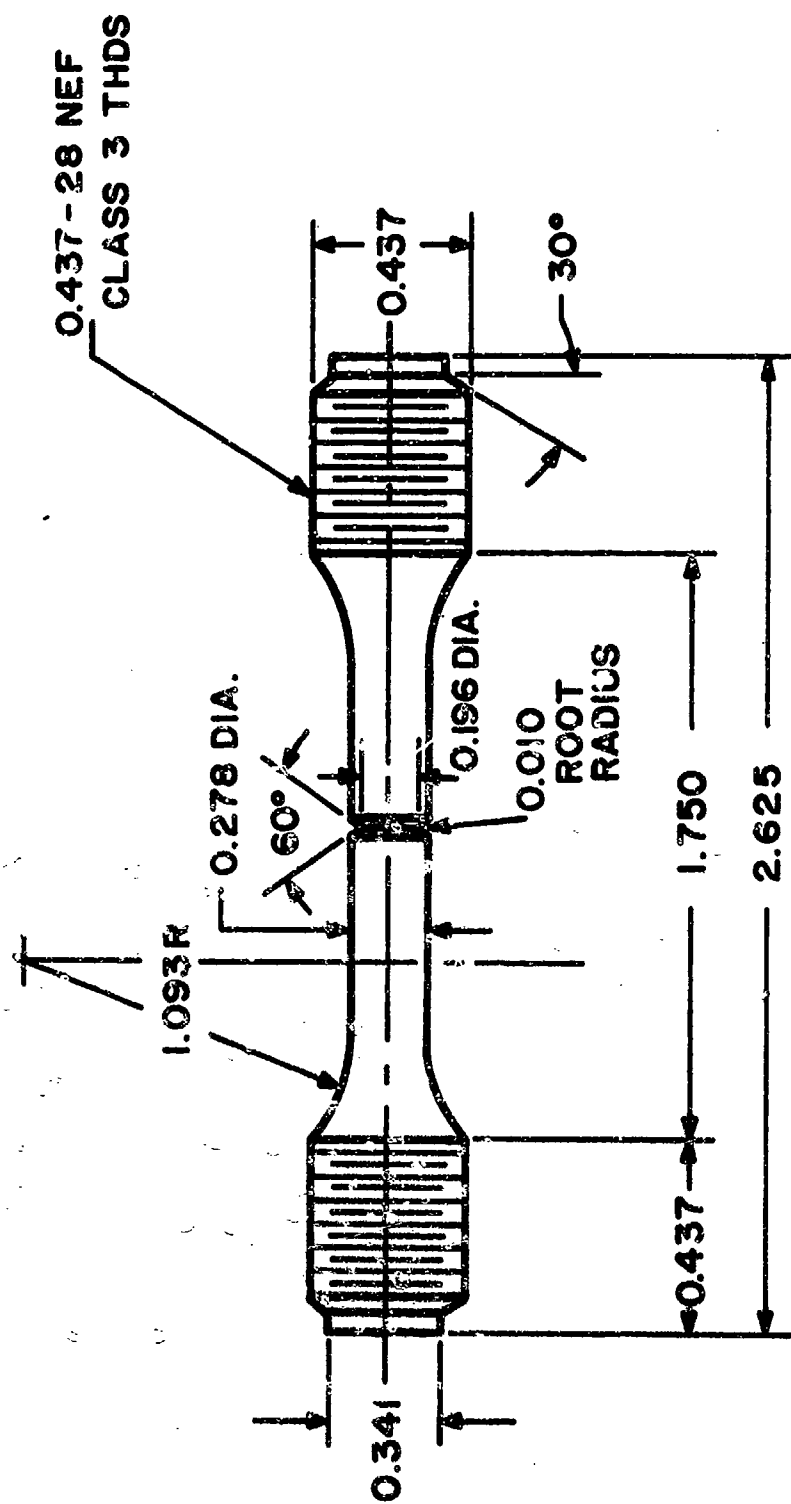


Figure 4. Notched Fatigue Specimen Configuration.

SECTION III PROCEDURE

The tensile and fracture toughness tests were conducted at room temperature and 250° F using either a Weidemann or an Instron tensile testing machine. Precracked compact tension stress corrosion specimens were tested at loads to give stress intensities of 16.3 and 20.3 KSI $\sqrt{\text{IN}}$ in Satec creep frames using continuous immersion in a 3.5 percent sodium chloride solution environment. Fatigue crack growth tests on compact tension specimens were performed in a laboratory environment with an "R" ratio of 0.1 using an MTS fatigue testing machine. All of the precracking of the compact tension specimens was performed using either an MTS or an Amsler Vibrophore fatigue testing machine with an "R" ratio of 0.1 and loads meeting the ASTM criteria. Both conventional smooth ($K_t = 1.0$) and notched ($K_t = 3.0$) fatigue specimens were tested in a laboratory environment with an "R" ratio of 0.1 and a frequency of 1800 cpm using a Schenck fatigue testing machine.

SECTION IV

RESULTS AND DISCUSSION

The individual and average tensile properties of the aluminum alloy 2124-T851 plate are listed in Tables I and II, respectively. Strength levels and elongations are approximately equal for each of the orientations at a constant temperature history with the exception of the short transverse orientation, which has significantly less elongation than the other two orientations. Table III presents the tensile data for 2024-T851 plate⁽¹⁾. Both the 2024-T851 and 2124-T851 alloys have similar strength and elongation levels. However, the 2024-T851 alloy appears to have slightly greater short transverse ductility. The ultimate strength of the 2124-T851 at 250° F was 86 percent of the room temperature value.

Tables IV and V contain the fracture toughness values for the 2124-T851 alloy. All of the fracture toughness tests conducted at room temperature and 250° F provided valid K_{IC} numbers. The change in test temperature from room temperature to 250° F had no effect on the K_{IC} values. Fracture toughness values for aluminum alloy 2024-T851⁽¹⁾ are listed in Table VI. The fracture toughness values for 2124-T851 are superior to those for 2024-T851.

Conventional smooth and notched fatigue data for 2124-T851 and 2024-T851⁽¹⁾ alloys are shown in Figure 5. From this data, the 2124-T851 alloy has slightly lower smooth fatigue properties and similar notched fatigue properties compared to the 2024-T851 alloy. The fatigue strengths for the 2124-T851 alloy at 10^7 cycles are 25 KSI for the smooth specimen configuration and 7.5 KSI for the notched specimen configuration.

Fatigue crack growth data for 2124-T851 and 2024-T851⁽²⁾ are presented in Figure 6. The 2124-T851 fatigue crack growth testing was conducted in a laboratory environment with an "R" ratio of 0.1 and a cycle

frequency of 25 cps. From Figure 6, it is evident that both alloys display identical crack growth rates.

Stress corrosion tests for the 2124-T851 alloy in the short transverse orientation (S-T) produced no failures after a 1000 hour exposure to a 3.5 percent sodium chloride solution environment. The precracked compact tension specimens were loaded at 16.3 and 20.3 KSI $\sqrt{\text{IN}}$. After completion of the tests, the specimens were broken apart and the precrack surfaces were examined. Slight amounts of general corrosion and pitting were identified on the precrack surfaces. A value for K_{ISCC} was not determined but since successful stress corrosion tests for the short transverse orientation (S-T) were conducted at 80 percent of K_{IC} , there should not be any stress corrosion problems with the 2124-T851 alloy.

The microstructure of the 2124-T851 was metallographically examined. Photomicrographs of the structure are presented in Figure 7.

TABLE I
TENSILE PROPERTIES OF ALUMINUM ALLOY 2124-T851 PLATE

Specimen No.	Orientation	Test Temperature (°F)	Ultimate Strength (KSI)	Yield Strength (KSI)	Elongation (%)
T4	Transverse	R.T.	69.6	61.8	6.9
T6	Transverse	R.T.	70.7	62.6	7.0
T7	Transverse	R.T.	70.1	62.0	6.5
T11	Longitudinal	R.T.	69.3	62.2	8.6
T15	Longitudinal	R.T.	69.4	63.2	7.7
T18	Longitudinal	R.T.	69.8	63.4	8.0
T22	Short Transverse	R.T.	68.8	62.6	4.0
T24	Short Transverse	R.T.	68.9	62.2	3.7
T27	Short Transverse	R.T.	69.1	62.1	3.4
T1	Transverse	250	61.3	58.1	8.9
T2	Transverse	250	60.0	57.2	10.6
T7	Transverse	250	59.7	56.6	8.9
T10	Longitudinal	250	59.3	56.4	11.2
T14	Longitudinal	250	60.3	57.2	11.6
T16	Longitudinal	250	60.2	57.1	11.9
T20	Short Transverse	250	59.5	---	4.8
T21	Short Transverse	250	59.5	56.0	3.3
T26	Short Transverse	250	59.4	55.7	4.4

TABLE II
AVERAGE TENSILE PROPERTIES OF ALUMINUM ALLOY 2124-T851 PLATE

Orientation	Test Temperature (°F)	Average Ultimate Strength (KSI)	Average Yield Strength (KSI)	Average Elongation (%)
Transverse	R. T. 250	70.1 60.3	62.1 57.3	6.8 9.5
Longitudinal	R. T. 250	69.5 59.9	62.9 56.9	8.1 11.6
Short Transverse	R. T. 250	68.9 59.5	62.3 55.9	3.7 4.2

TABLE III
TENSILE PROPERTIES OF ALUMINUM ALLOY 2024-T851 PLATE (1)

Orientation	Test Temperature (°F)	Ultimate Strength (KSI)	Yield Strength (KSI)	Elongation (%)
Longitudinal	R. T.	69.7	63.4	9.2
	200	64.0	58.6	11.0
	300	58.4	56.2	12.7
Transverse	R. T.	69.7	63.5	6.3
	200	63.1	58.3	7.3
	300	57.6	54.1	7.0
Short Transverse	R. T.	68.7	61.0	5.3
	200	63.8	56.4	5.7

TABLE IV
FRACTURE TOUGHNESS (K_{IC}) PROPERTIES OF ALUMINUM ALLOY
2124-T851 PLATE
W = 2.00 Inch and B = 1.000 Inch

Specimen No.	Specimen Orientation	Test Temperature ($^{\circ}$ F)	$\frac{P_{max}}{P_Q}$	$2.5 \left(\frac{K_Q}{Y_S} \right)^2$ (IN)	Fracture Toughness K_{IC} (KSI \sqrt IN)
FR1	T-L	R.T.	1.015	0.517	28.2
FR5	T-L	R.T.	1.021	0.471	26.7
FR9	T-L	R.T.	1.000	0.464	26.9
FR10	L-T	R.T.	1.037	0.670	32.1
FR15	L-T	R.T.	1.026	0.666	32.0
FR18	L-T	R.T.	1.045	0.739	33.7
FR19	S-T	R.T.	1.000	0.440	26.0
FR24	S-T	R.T.	1.000	0.433	25.8
FR27	S-T	R.T.	1.023	0.397	24.7
FR2	T-L	250	1.000	0.590	27.7
FR6	T-L	250	1.003	0.565	27.1
FR8	T-L	250	1.000	0.557	26.9
FR12	L-T	250	1.040	0.853	33.3
FR14	L-T	250	1.054	0.884	33.9
FR16	L-T	250	1.043	0.783	31.9
FR22	S-T	250	1.000	0.528	26.2
FR26	S-T	250	1.000	0.465	24.6

TABLE V
 AVERAGE FRACTURE TOUGHNESS (K_{IC}) PROPERTIES OF
 ALUMINUM ALLOY 2124-T851 PLATE
 $W = 2.000$ Inch and $B = 1.000$ Inch

Specimen Orientation	Test Temperature ($^{\circ}F$)	Fracture Toughness K_{IC} , (KSI \sqrt{IN})
T-L	R. T. 250	27.3
		27.2
L-T	R. T. 250	32.6
		33.0
S-T	R. T. 250	25.5
		25.4

TABLE VI
FRACTURE TOUGHNESS PROPERTIES (K_{IC}) OF
ALUMINUM ALLOY 2024-T851 (1)

Specimen Orientation	Test Temperature ($^{\circ}$ F)	Fracture Toughness K_{IC} (KSI \sqrt IN)
L-T	R. T.	27.1
L-T	200	26.8
T-L	R. T.	21.5
T-L	200	21.7

TABLE VII
FATIGUE PROPERTIES OF 2124-T851 ALUMINUM ALLOY

Specimen No.	Specimen Type	Test Frequency (CPM)	R Ratio	Max. Stress (KSI)	Cycles to Failure
S1	Smooth	1800	0.1	60	1.6×10^4
S2	Smooth	1800	0.1	80	-----*
S3	Smooth	1800	0.1	40	1.5×10^3
S4	Smooth	1800	0.1	50	4.9×10^4
S5	Smooth	1800	0.1	30	3.1×10^6
S6	Smooth	1800	0.1	25	1.0×10^7
S7	Smooth	1800	0.1	70	7.0×10^2
S8	Smooth	1800	0.1	65	9.5×10^3
NF1	Notched	1800	0.1	30	1.4×10^4
NF2	Notched	1800	0.1	20	4.8×10^4
NF3	Notched	1800	0.1	10	1.4×10^6
NF4	Notched	1800	0.1	60	2.4×10^3
NF5	Notched	1800	0.1	15	1.5×10^5
NF6	Notched	1800	0.1	7.5	1.1×10^7
NF7	Notched	1800	0.1	40	4.8×10^3
NF8	Notched	1800	0.1	30	2.0×10^4

* Specimen failed before reaching the maximum stress.

Note: All specimens were oriented in the Transverse direction and were tested in Laboratory environment.

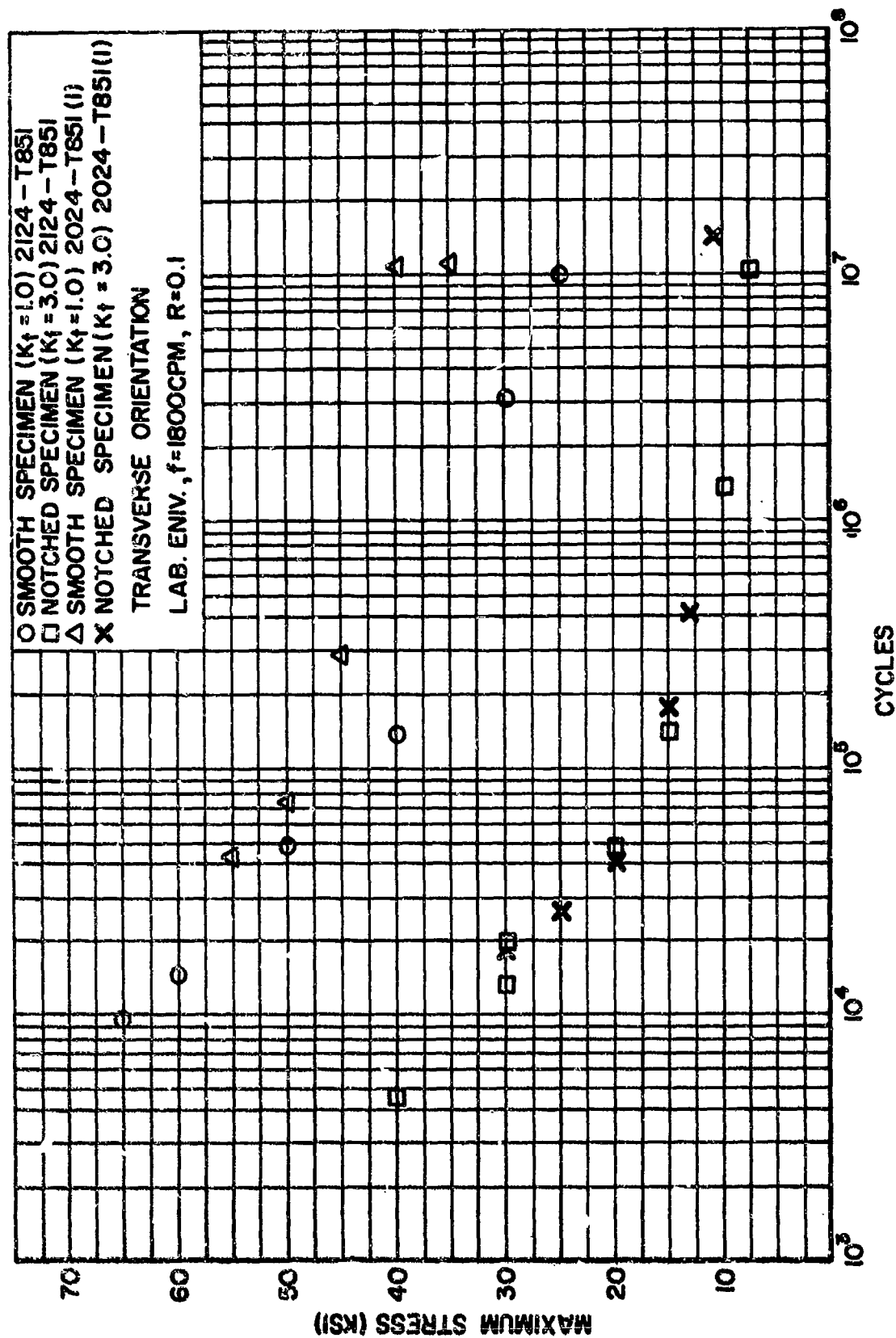


Figure 5. Fatigue Crack Growth Data for Aluminum Alloy 2124-T851.

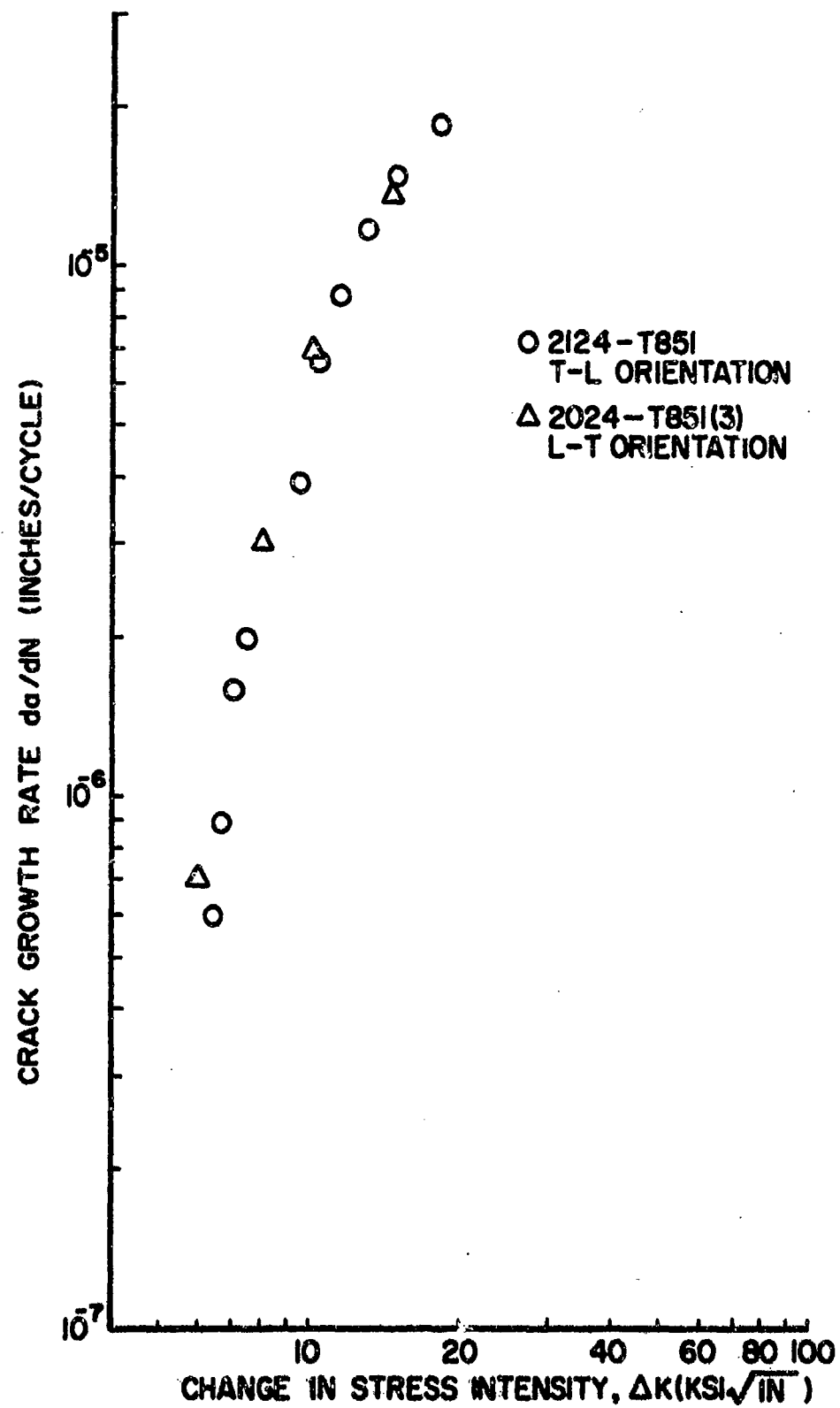
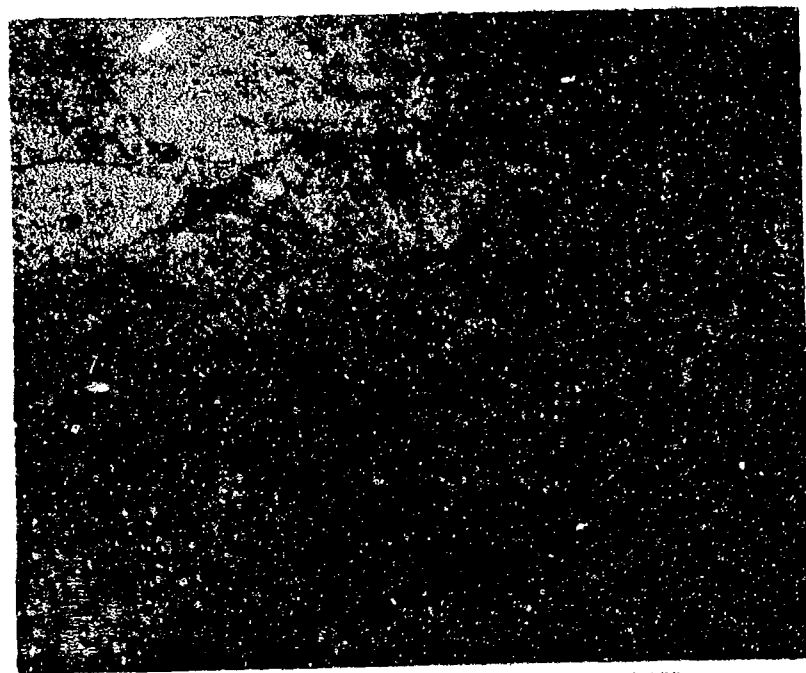


Figure 6. Fatigue Crack Growth Data for Aluminum Alloy 2124-T851.

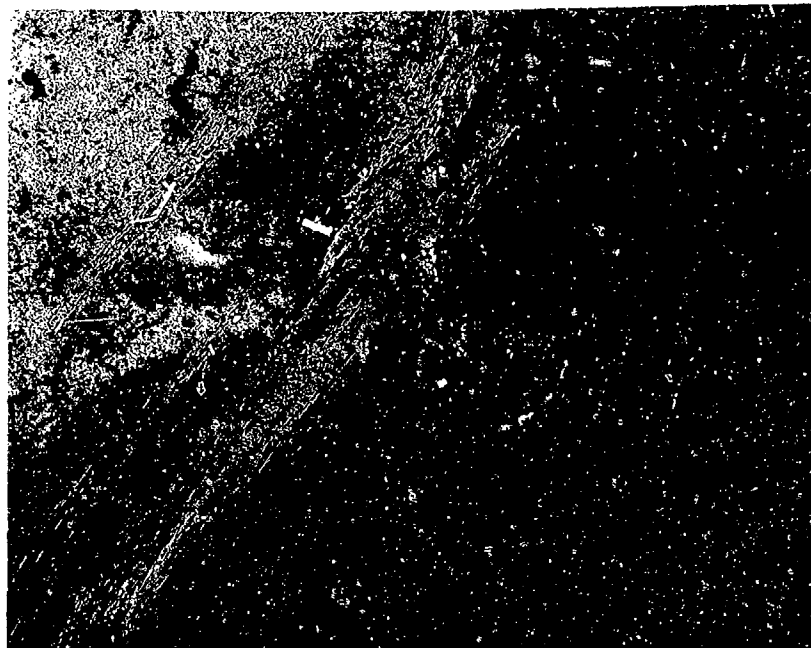


(a) Longitudinal Orientation, 160X



(b) Transverse Orientation, 160X

Figure 7. Microstructure of Aluminum Alloy 2124-T851 Thick Plate.



(c) Short Transverse Orientation, 160X

SECTION V

SUMMARY

Based on test results from a single plate of 2124-T851, the room temperature and 250°F tensile properties for 2124-T851 compare favorably with tensile properties for 2024-T851. However, the short transverse ductility for 2024-T851 appeared to be slightly better than that of 2124-T851.

The fracture toughness (K_{IC}) values for 2124-T851 was superior to the corresponding values for 2024-T851 in all conditions tested.

Fatigue data for 2124-T851 and 2024-T851 show that the 2024-T851 alloy has slightly better smooth fatigue properties and that both alloys have similar notched fatigue properties. Fatigue crack growth rates are identical for both alloys.

The stress corrosion resistance of 2124-T851 appears adequate based on the short transverse (S-T) specimens which passed stress corrosion tests at 80 percent of K_{IC} in a 3.5 percent sodium chloride solution environment.

In summary, aluminum alloy 2124-T851 offers superior fracture toughness properties. The 2124-T851 has similar tensile properties with possibly less short transverse ductility, slightly lower smooth fatigue properties and comparable notched fatigue properties, and identical fatigue crack growth properties compared to the properties of the 2024-T851 alloy. The 2124-T851 alloy also possesses very good stress corrosion resistance in the short transverse (S-T) orientation.

Admittedly these results are based on only a single plate from each alloy. Either or both of these plates may not exhibit the types of properties that would result if a statistically significant number of heats or plates were tested. It is possible the 2024 plate data used for comparisons was from a plate whose mechanical properties were on the high side of the normal

scatter band for 2024 while the 2124 plate tested herein possessed properties that were in the mid range or low side of the scatter band for 2124 plate data. Therefore, the findings presented herein may be revised when a broader data based is developed.

Nevertheless, no explanation of the apparent lower short transverse ductibility and smooth fatigue strength of the 2124-T851 can be given if, in fact, such differences were real. In any case the test program failed to confirm the claims of superior short transverse properties of the 2124 alloy.

SECTION VI

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2. Damage Tolerant Design Handbook, MCIC-HB-01, December 1972.